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Penetration of Fallout Gamma Radiation

A STUDY of gamma-ray penetration has been conducted by the Bureau for the Civil Effects Test Group of the Atomic Energy Commission. Measurements were made after detonations at the Nevada Proving Grounds, providing on-the-scene experimental data on the effects of fallout. This study, by W. F. Titus[1] of the radiation theory group, is one of the first attempts to make field measurements of fallout in arrangements which lend themselves to a theoretical approach. By allowing an adequate comparison between experimental data and theoretical calculations, this work provides a basis for extending theory to configurations more elaborate than those for which predictions are now possible. Results of this investigation should thus be very useful in the development of suitable shelters against radiation from nuclear weapons.

A central problem of radiation shielding is the prediction or estimation of radiation effects at each point in the shielding material. This problem has been attacked frequently in the past by exposing several thicknesses of absorbent material to a radiation source and monitoring the transmitted radiation. However, these tests have provided the answer to specific shielding questions in complicated configurations only, and it was not possible to extrapolate their results to different conditions. As the propagation of radiation depends in part upon the geometry of the medium, a simple construction would yield results which are more widely applicable. For this reason, the Bureau chose as its test geometry an infinite plane uniformly covered by fallout. A calculation of the penetration for this simplified situation, which is in effect an infinite homogeneous medium exposed to a plane-isotropic source, had been previously worked out by the radiation theory group. This calculation formed the theoretical basis with which experimental results were compared.

Concrete, one of the materials most suitable for shielding applications, was the medium chosen for study. Penetration was experimentally determined in a stack of seven reinforced concrete slabs, constructed in a pit, $8\frac{1}{2}$ ft^2 and 40 in. deep. Geiger counters inserted into spaces between the slabs measured the dose rate as a function of depth. The total dose accumulated at each level was monitored by pocket or film dosimeters. In addition to the detectors within the concrete mass, detectors were mounted on a steel tower 20 ft from the pit.

At almost all times the dose rate under 3 in. of concrete was found to be approximately $\frac{1}{10}$ that at 9 ft above the ground. Each additional 6 in. of concrete reduces dose rate by another factor of approximately $\frac{1}{10}$. The overall attenuation in 22 in. of concrete is

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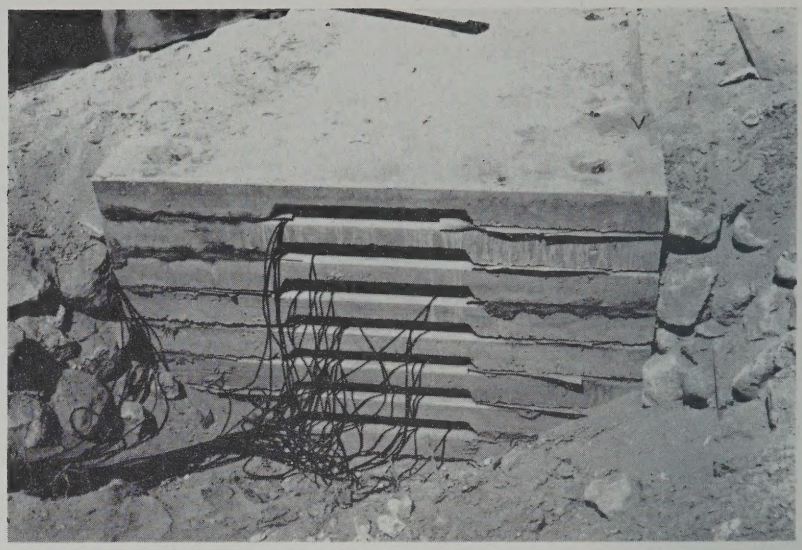
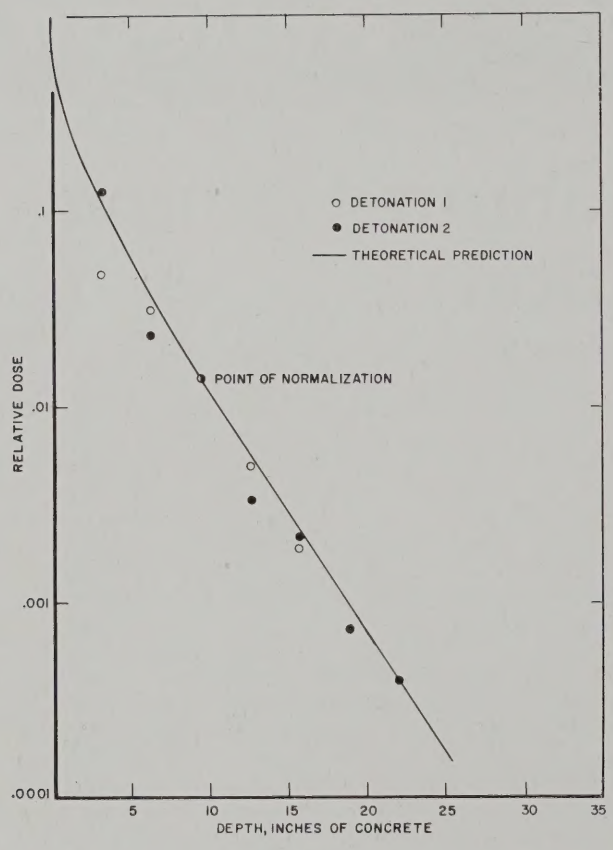


Stack of seven concrete slabs in which the penetration of gamma radiation was measured. Wiring connects detectors to monitoring equipment, which was located in an underground vault for protection from fallout.



Comparison between theoretical calculations and experimental data for the penetration of gamma radiation in concrete 1 hr after a nuclear detonation. The experimental values, which have been normalized to the calculated curve at a depth of 9.5 in., show a good agreement with theory.

therefore about 1 ten-thousandth of the dose rate at 9 ft above the ground. This experimentally observed decrease in dose rate with depth shows good agreement with the calculated decrease in dose rate for an ideal situation.

The detection system was a remote radiation-monitoring system designed by the Bureau. Dose-rate detectors were connected with equipment in nearby underground vaults. From these underground stations, data were transmitted by direct field lines to a control point where information was automatically checked and catalogued.

Experimental data were obtained in this way after each of two nuclear explosions. Immediately after the test shot, dose rates were measured in the various levels of the concrete and at the tower. Measurements were made every 12 min during the first 2 hr, then every ½ hr for the next 3 hr, and finally every hour until the dose rates in the lower levels were below 1 mr/hr. These measurements were performed at 2,000 yd from one nuclear test shot and 4,000 yd from the other.

Results of this work indicate that the time dependence of the dose rate above ground is $t^{-1.2}$, which is in agreement with precise dose-decay measurements made elsewhere in the area. The fallout incident on the concrete is therefore considered typical. The dose rate under 9 in. of concrete decreases more rapidly with time than this surface dose rate during the first 10 or 12 hr after the blast. This decrease is probably due to the more rapid decay of the higher energy components of the gamma spectrum at the surface.

During the first few hours, the penetration of fallout radiation is very like that of a 2-Mev plane isotropic gamma source. At later time, penetration falls off, resembling a 1-Mev plane isotropic source.

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[1] *Now on the faculty of Dartmouth College, Hanover, N.H.*

FITTING STRAIGHT LINES TO CUMULATIVE DATA

THE METHOD of least squares is used extensively by physicists, chemists, and engineers for the fitting of theoretical or empirical curves to experimental data. In the simplest, and perhaps the most common, of these curve-fitting situations the experimental points representing the data fall along an approximately straight line. However, for the accepted statistical fitting formulas to be valid in this instance, the data must satisfy certain requirements. The most important of these is that the experimental errors affecting various points be mutually independent.

As this condition is very frequently violated, the Bureau has made a study of the fitting of straight lines to *cumulative* data. This work by John Mandel has shown that if data subject to cumulative types of error are treated by the ordinary formulas of "linear regression," the true fluctuations of the process as well as the uncertainty in the estimated rate of the process are seriously underestimated.[1]

This situation is illustrated by the following example. Suppose an economy-minded motorist keeps a record of his mileage and the associated gasoline consumption. As long as the car maintains a reasonably uniform gas-mileage rate, the total number of miles recorded on the odometer will be proportional to the number of gallons of gasoline consumed since the car's purchase. Thus, a plot of gallons of gasoline (dependent variable) versus mileage (independent variable) will be a straight line passing through the origin. Deviations from the line will occur because the conditions of driving, not always being identical, cause fluctuations in the rate of gasoline consumption. It might be thought that the best statistical measure of the fluctuations in gasoline consumption rate would be given by the "standard error of estimate" derived from a linear regression analysis of gasoline consumption versus mileage. However, such a measure would in fact be a very serious underestimate because the measurements on which the graph is based, in this case the cumulative quantities of gasoline, are not independent. Furthermore, the factor of underestimation increases as the number of points on the plot increases. Indeed, if during any period the rate of gasoline consumption were excessively high, and in the following period normal, the cumulative gasoline consumption at the end of this second period would still bear the mark of the high consumption during the former period.

Many scientific processes are similar in nature to the example just described. The study of rates of chemical reactions generally involves an entire series of successive measurements carried out on a single system of reacting substances. Any fluctuation in the rate of the process affects not only the measurement immediately following the fluctuation, but also all subsequent measurements. Wherever measurements of a cumulative nature are involved, the possibility of nonindependent fluctuations must be considered.

Theoretical studies have shown that for the case of equidistant spacing along the axis of the independent variable, the application of the ordinary least-squares formulas to data with cumulative-type errors leads to an estimate of the standard error of the slope that is too small by a factor of $2\sqrt{N}$, where N is the number of points. Thus for 50 equally spaced points the slope would be estimated to be 14 times more precise than it actually is. Fortunately, with at least 30 points the data themselves readily betray their cumulative nature. Unlike independent measurements, data with cumulative errors show long series of successive points all of which are on one side of the fitted line.

A criterion for judging whether the situation under consideration involves independent or cumulative data can therefore be based on the number of times the line joining successive observations crosses the fitted line. When data are cumulative the number of intersections is, of course, relatively small.

This theory has been applied to the results obtained in a study of the relation between mechanical stress and double refraction in optical glasses.[2] A graphical representation of this relation indicated that the experimental errors were predominantly cumulative. Data were therefore treated accordingly, and an overestimation of the precision of experimental findings was avoided.

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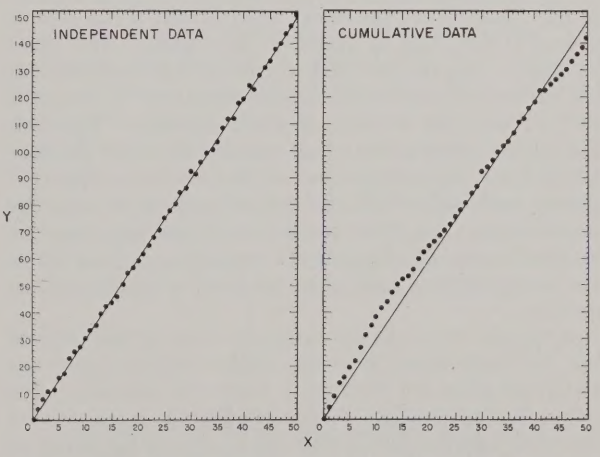
[1] *For further information, see* Fitting a straight line to certain types of cumulative data, *by John Mandel, J. Am. Stat. Assoc.* **52,** *552 (1957).*

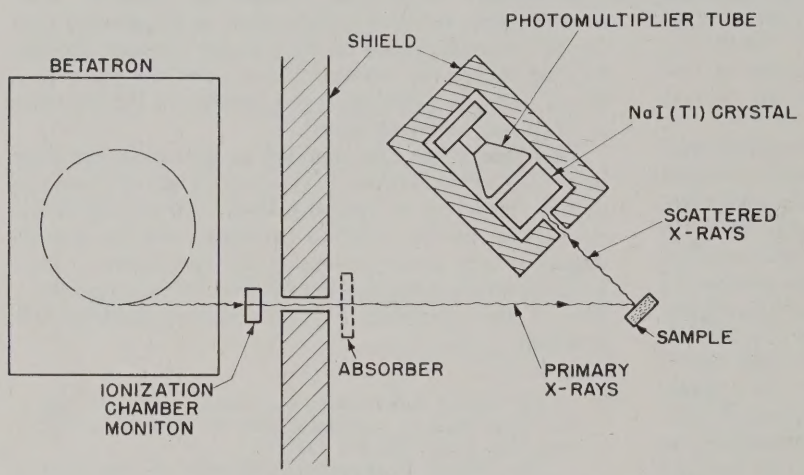
[2] The relative stress-optical coefficients of some NBS optical glasses, *by R. M. Waxler and Albert Napolitano* **59,** *121 (1957) RP2779.*



A comparison between independent and cumulative data fitted to a straight line. Cumulative data can be recognized by long series of successive points lying to one side of the fitted line. A line joining these points will cross the fitted line very infrequently in contrast to the line joining independent points, which crosses the fitted line many times.

ELASTIC SCATTERING OF X-RAYS

THE elastic scattering of X-rays has been the subject of a detailed investigation conducted by the Bureau's high-energy radiation group for the Air Force Office of Scientific Research. This project is part of an overall program directed at understanding the basic interactions of X-rays with matter in general, and in this instance with *nuclear* matter in particular. A large part of the effort in the scattering project has been concentrated on a study of the elastic scattering process in the region of the giant resonance for photon absorption by the nucleus.



Experimental arrangement employed in studying the elastic scattering of X-rays.

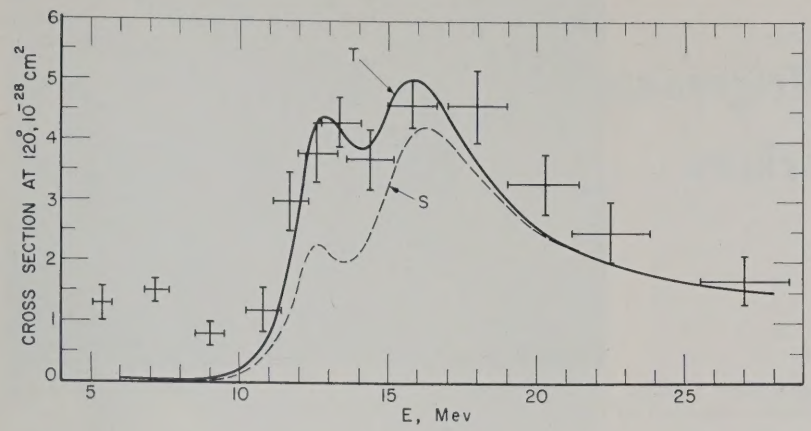
The giant resonance is a hump in the cross section, or the probability, for X-ray absorption; it has a peak near 15 Mev and is about 5 Mev wide. The exact positions, magnitudes, and widths of the cross sections for various elements have been extensively investigated and are still the subject of much interest. The total absorption cross sections are usually obtained by summing the cross sections for all the reactions that take place, each of which is determined in a separate experiment. An alternate approach has been applied by the Bureau, in which elastic-*scattering* cross sections are measured and related to the total *absorption* cross section.

A typical cross-section curve obtained by this method can be understood in terms of the various processes which produce the elastically scattered photons. For example, the nuclear elastic scattering cross section expected for the lowest-energy X-rays is the same as that for a scattering center having the same charge and mass as the nucleus. At slightly higher energies the scattering cross section increases as photons start to be absorbed and re-emitted by discrete nuclear levels. At these energies (1 or 2 Mev) the scattering cross section is still very small, but it increases rapidly in the range 5 to 7 Mev as the number of levels available in a given energy interval increases. At about 7 Mev the incident X-rays have enough energy to eject a neutron from the target nucleus. Therefore the scattering cross section falls rapidly because the nucleus now prefers to lose its excitation energy by neutron rather than X-ray emission. At slightly higher energies, the scattering results primarily from the oscillations of the neutrons and protons within the nucleus. At these energies (10 to 25 Mev) the cross section goes through the maximum known as the giant resonance. At even higher energies tht elastic scattering cross section depends only on the effective number of charges within the nucleus.

Experimental Procedure

The Bureau's 50-Mev betatron was used as a source of X-rays in the elastic scattering experiments. These X-rays were directed at targets of various materials, and the scattered X-rays were detected by a sodium iodide scintillation spectrometer. The spectrometer was adjusted to register only elastically scattered photons, that is photons scattered without losing any energy. Measurements were made as the X-ray energy was varied from 5 to 40 Mev, with the general results described above.[1]

The energy at which the giant resonance occurs is related to the dimensions of the nucleus. If the nucleus is considered as a classical oscillator with the nuclear charge confined to a region determined by its radius, its resonant frequency would be expected to vary inversely as its radius. The energies at which the giant resonances were observed in the Bureau's scattering experiments have this dependence.

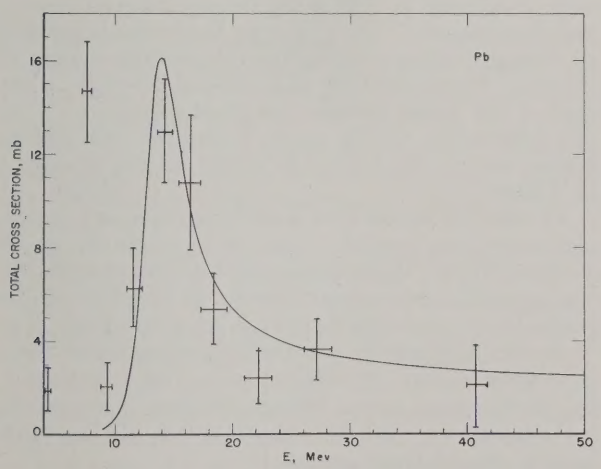


Elastic scattering cross sections for tantalum (experimental points) compared with scattering cross sections calculated from neutron yield data (curves). Curve S was obtained assuming that the resonances are uncorrelated, curve T assuming that resonances represent classical charge oscillations along perpendicular axes. Curve T appears to fit the experimental data better than S.

Interpretation of Results

The magnitude and shape of the observed scattering cross sections were interpreted in terms of measurements made of total absorption cross sections. This was made possible by an optical theorem which relates the forward scattering cross section at a given energy to the total absorption cross section at all energies. Satisfactory agreement between the two kinds of measurements was obtained.

In order to make such comparisons, it was necessary to make some assumptions concerning the angular distribution of the scattered radiation. These assumptions are (1) that the scattering is produced by a classical oscillator, and (2) that the angular distribution does not depend on the nuclear orientation relative to the incident X-ray beam. For the medium and heavy elements studied, good agreement was obtained between the experimental scattering results and those predicted from total absorption cross sections. For light nuclei, such as aluminum and magnesium, the measured elastic-scattering cross sections are much larger above 25 Mev than would be predicted from the measured absorption cross sections. The study of the light nuclei is continuing to determine whether one or both of the above assumptions is in error.



Measurements of the elastic scattering of X-rays by lead at various energies (experimental points) show a good agreement with the scattering calculated from neutron yield studies (solid line). Experimental points show the energy spread and the uncertainty in recorded counts.

Studies of Nonspherical Nuclei

Attention is now being focused on nuclei known not to be spherical. Here assumption (2) is not expected to hold. Recently Bureau scientists have confirmed the predictions of Danos [2] and Okamoto [3] that the giant resonance for a deformed nucleus really consists of two resonances, associated with the one long and two short axes of the nuclear ellipsoid and separate by an amount depending on its eccentricity.[4]

The elastic scattering cross sections for tantalum, an ellipsoidal nucleus, were subsequently measured.[5] Experimental results were compared with two predicted cross sections. One predicted curve was obtained from the measured neutron yield cross section by assuming that all directions in the nucleus are equivalent. The other predicted curve was obtained by associating the two resonances of the neutron yield cross section with charge oscillations along the perpendicular axes of the nuclear ellipsoid. The experimental points were found to agree better with the second prediction.

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[1] Nuclear elastic scattering of photons, *by E. G. Fuller and Evans Hayward, Phys. Rev.* **101**, *692 (1956).*

[2] *Nuclear Physics* **5**, *23 (1958).*

[3] *Progr. Theoret. Phys. (Kyoto)* **15**, *75 (1956).*

[4] Shape of the atomic nucleus, *NBS Tech. News Bul.* **43**, *45 (1959).*

[5] Elastic scattering of photons by tantalum, *by E. G. Fuller and Evans Hayward, Phys. Rev. Letters* **1**, *465 (1958).*

Providing Liquid Refrigerants to Research Workers

Unloading liquid helium flown 1,700 miles from Denver to Washington. Over 90 air trips have been made to supply the Washington Laboratories with helium liquefied at the Boulder (Colo.) Laboratories.

Commercial Procurement, Long-Range Transportation, and Centralized Handling Accelerate Scientific Investigations

THE Bureau is engaged in a Program of Free Radicals Research in which emphasis is placed on temperatures in the region of 77° down to 1° K.[1] Maintaining these temperatures, where the highly reactive molecular fragments are stabilized, requires the use of liquefied gases. Each week the program uses approximately 100 liters of liquid helium, 800 liters of liquid nitrogen, and 50 liters of liquid hydrogen—quantities it is not always feasible to produce at the Bureau. Purchasing liquefied gases from commercial sources and even, when necessary, transporting them over long distances has provided a solution to the problem which is both economically acceptable and dependable.

The Bureau has coupled with this approach to procurement a plan which frees research scientists from the time-consuming details involved in handling low-temperature liquids. The system, which has been operating successfully for over 2 years, provides overall economy and accelerates research. Under this plan, instead of the scientist transferring the liquid himself, personnel trained in the operation of low-temperature apparatus deliver the liquid refrigerants to the experimenter on a scheduled basis as they are needed. This specially trained staff, headed by A. K. Stober with the assistance of M. C. Jones, is also responsible for the procuring, storing, handling, and transferring of low-temperature liquids, including hydrogen, helium, nitrogen, and oxygen.

Commercially obtained liquid hydrogen to meet the needs of the Free Radicals Research Program is loaded on a truck in a specially designed Dewar. Hydrogen is shipped without nitrogen shielding under 10-psi pressure with very little loss.

Procurement

A supplement to the liquid-helium supply available at NBS Washington was found in the liquefaction facility operated by the Bureau's Cryogenic Engineering Laboratory in Boulder, Colo. Difficulties such as Dewar damage, vibration, and sloshing, which arise in truck or rail transportation over long distances, are now eliminated by flying the helium between Denver and Washington.[2] Over 90 trips have been completed to date, providing a regular and dependable supply of helium. Transportation adds only a fraction to the cost of the liquid helium, the most expensive of the low-temperature liquids used. Losses for each 50-liter Dewar during the 1,700-mile flight amount to only 1 to 2 liters.

To meet the demand for liquid hydrogen, a commercial source was located. High-purity parahydrogen is shipped directly to the Bureau without nitrogen shielding in special pressurized Dewars, in which it can be stored if an immediate transfer is not convenient. The hydrogen is shipped by a specially built grounded truck, on a week's notice, in 150-liter quantities. Transporting the hydrogen over a 500-mile distance increases the price by about one-half. The loss rate during shipment is about 3 liters per day.

Liquid nitrogen, now a relatively inexpensive refrigerant, is also purchased commercially. Individual 50-liter containers are delivered directly to requisitioners—a scheme which eliminates extra handling. To provide a continuous supply between deliveries, which are made on 24 hours' notice, a large quantity of nitro-

Part of the central storage area for liquid helium and hydrogen. A. K. Stober (right) is transferring liquid helium, stored in a 50-liter Dewar, to a taped strip-silvered Pyrex Dewar which M. C. Jones (left) will deliver to a member of the scientific staff.

gen, from which scientists make their own transfers, is stored. As nitrogen is obtained locally, no charge is made for delivery and losses are negligible.

Although liquid oxygen is available in quantity, purchases are made only upon request.

Storage

Between procurement and delivery to individual laboratories, the nitrogen and the helium supplies are housed in a central storage area. This facilitates the nitrogen-shielding of helium Dewars, limits the amount of handling required, controls the frequency of transfers, and permits a closer check on equipment. Hydrogen, because of its hazardous nature, must, of course, be stored separately.

Liquid nitrogen to be used for liquefaction of helium is stored in 300-gal quantities, with a loss of 3 to 4 liters per day. The nitrogen delivered to requisitioners is stored in 50-liter commercial-type containers, with a loss rate of approximately 1 to 1.5 liters per day.

Both helium and hydrogen are stored in 50-liter nitrogen-shielded commercially manufactured Dewars. Losses over a 24-hr period are 0.1 to 0.4 liter for hydrogen and 0.3 to 0.8 liter for helium. The dimensions of these storage containers were carefully controlled in manufacture to allow siphoning equipment to be used most efficiently in all transfer operations.

Transfer

Transfer techniques are an essential part of the overall operation. As it is very difficult to transport a helium or hydrogen Dewar and lift (combined weight 525 lb) to the various laboratories, delivery is accomplished by a double-transfer method in which liquid is transferred from the storage Dewar to a transport Dewar, and from the transport Dewar to the experimental apparatus. The loss during a complete transfer is about 250 cm^3. As helium and hydrogen have low heats of vaporization, these transfers require the use of a vacuum-insulated transfer siphon.

The transport vessels used to deliver the liquids to the laboratories are well-taped strip-silvered Pyrex Dewars, ranging in capacity from 2 to 3 liters. Over 2,500 transfers have been made to date in this way without Dewar loss or injury to personnel.

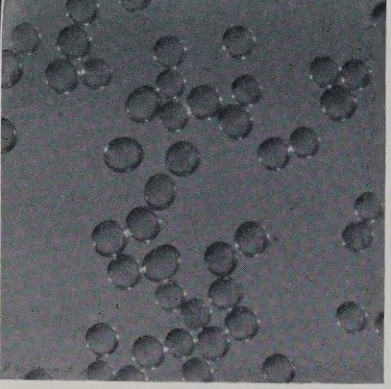
With this effective program for supplying low-temperature liquids to its research staff, the Bureau has demonstrated the desirability of incorporating refrigerant handing into a separate operation. By relying on trained and experienced personnel, such centralization has guaranteed efficient and economical execution of the multitudinous details involved in procurement, storage, and transfer. The success of this particular effort, with its dependence on outside sources of supply, has paved the way for more widespread use of low-temperature liquids through commercial procurement. It also opens low-temperature research frontiers to investigators having no liquefaction equipment at their disposal.

The Bureau wishes to acknowledge the cooperation of United Airlines; the Linde Company, Division of Union Carbide Corporation; and Hofman Laboratories in making this program a success.

[1] Low temperature storage of free radicals, *NBS Tech. News Bul.* **40**, *112 (1956)*; Free Radicals Research Program, *NBS Tech. News Bul.* **41**, *1 (1957)*.

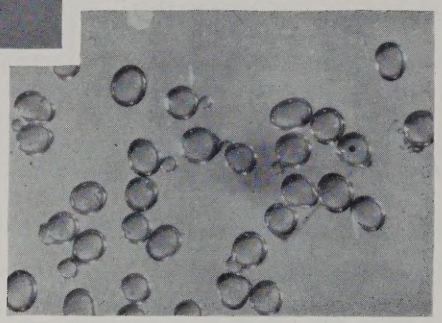
[2] Helium liquefaction and transportation, *NBS Tech. News Bul.* **43**, *30 (1959)*.

The final step in supplying liquefied gases to the scientific staff. M. C. Jones is transferring helium to L. J. Schoen's experimental apparatus from the taped Dewar in which it was delivered to the laboratory. A special group of employees experienced in the handling of low-temperature liquids carries out all such operations.



Standard Samples of Glass Spheres

for calibrating sieves



Only spherical glass beads (top) are used as standard samples for sieve testing. Irregular-shaped beads (bottom) can pass through the square or slightly rectangular sieve openings even though one dimension of the bead exceeds the length of the opening.

HIGHER accuracy in the calibration of testing sieves can now be achieved with two standard samples of glass spheres[1] available from the Bureau. With these standards of certified particle-size distribution, the effective opening of a sieve can be easily measured in any laboratory equipped for normal sieving operations. A uniform basis is thus provided for determining particle size.

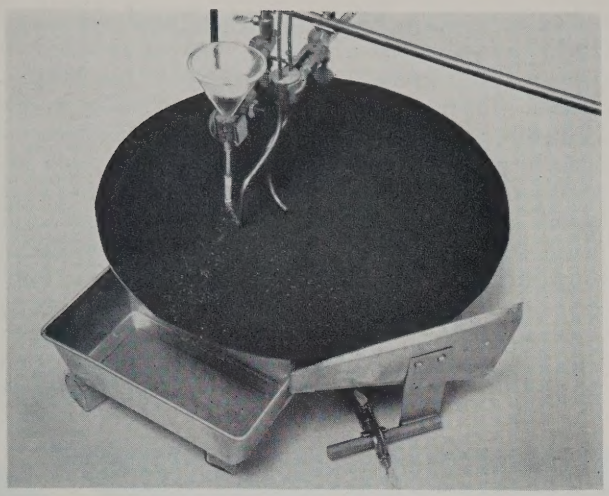
Requirements of practically every commercial powdered or granular material—from cosmetic face powder to solid adsorbents used in sugar refining—include maximum and/or minimum limits of the particle sizes. In particular, knowledge of particle-size distribution is often required both for quality control and research purposes. Such widely diverse industries as foundries, petroleum laboratories, sugar refineries, soap manufacturers, cement makers and users, roof-material companies, and chemical firms use sieves both for checking particle size and for measuring particle-size distribution.

In the past, discrepancies were often found when sieve analyses from different laboratories were compared.[2] One cause of this problem has been traced to a method of calibrating testing sieves, which involves the optical measurement of a small number of openings from which the average sieve opening is computed. If the size of the sieve openings is not quite uniform throughout, the effective opening will be slightly larger than the average. To eliminate this difficulty, F. G. Carpenter and V. R. Deitz of the Bureau's Bone Char Research Project developed the glass sphere standards.[3]

To calibrate any set of sieves, the sieves are assembled in a pile with the sieve containing the largest openings on top. Then, the entire sample of glass spheres is placed on the top sieve and shaken until the rate of bead passage is practically zero, just as in the sieve analysis of an unknown material. The beads that remain on each sieve are carefully weighed and the weight percentages calculated. The effective sieve openings can then be determined from calibration data supplied with the samples.

To prepare the standard samples, R. K. Kirby of the length laboratory obtained glass beads manufactured for projection screens and highway markings. As not all of these beads were spherical, it was necessary to eliminate the odd-shaped ones. This was accomplished by placing the particles a few at a time on a rotating, inclined disk. The spherical beads rolled straight down the incline into a trough, whereas the misshapen beads rolled in curved paths or tumbled and were carried along by the rotation and fell into a discard box.

To calibrate sieves, a complete set of glass spheres is deposited on the top sieve and shaken until the rate of bead passage is virtually zero. F. G. Carpenter places nest (set) of sieves in a shaking machine.



To obtain glass beads for standard samples, spherical beads must be separated from other-shaped particles. When the particles are funneled on to a rotating, inclined disk, the spherical beads roll in a straight line, while the other beads roll in a curved path.

The next step was to obtain spheres of continuous size distribution. For this operation, the glass spheres were carefully sieved into the closest sieve fractions, after which known weights of each fraction were combined into one composite mixture. By using a riffle-type 1 to 8 sample divider, this large mixture was then divided into small, almost identical samples, which were placed in small bottles.

To check on size distribution, random samples were taken, and the diameters of many particles from each sieve fraction were directly measured with a projection microscope. Standard sample 1017 is made up of glass spheres having diameters ranging from 50 to 230 μ (and can be used to calibrate testing sieves U.S. No. 270 through U.S. No. 70), while standard sample 1018 has spheres with diameters from 210 to 980 μ (and can be used to calibrate sieves U.S. No. 70 through U.S. No. 20). These data are included on a certificate of calibration supplied with each sample. The reproducibility of the calibration is within ± 5 percent for standard sample 1017 and ± 2 percent for sample 1018. A third sample with larger-sized spheres will be available at a later date.

[1] *The samples may be obtained (for $9.50 each) from the Supply Division, National Bureau of Standards, Washington 25, D.C. Over 600 different standard materials of chemicals, ores, ceramics, metals, and other substances are distributed by the National Bureau of Standards. Information is contained in Standard Materials, NBS Circ. 552 (third edition), which may be obtained by writing to the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. (35 cents).*

[2] Methods of sieve analysis with particular reference to bone char, *F. G. Carpenter and V. R. Dietz, J. Research NBS* **45,** *328 (1950) RP2143.*

[3] Glass spheres for the measurement of the effective opening of testing sieves, *F. G. Carpenter, and V. R. Dietz, J. Research NBS* **47,** *139 (1951) RP2238. Patent No. 2,693,706.*

NEW PUBLICATION:

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure

THIS HANDBOOK contains the latest recommendations of the National Committee on Radiation Protection and Measurements (NCRP) concerning the maximum permissible internal exposure of the human body to radioisotopes. These recommendations represent a revision of those published by the NCRP in 1953.

The 1953 recommendations were for occupational exposure, 24 hrs per day, continuously for 70 years. Prepared by the subcommittee on Permissible Internal Dose, the study took five years to complete and included nearly 75 radioisotopes.

The work has continued at an accelerated pace since 1953 with the added cooperation of the International Commission on Radiological Protection (ICRP). The present Handbook includes maximum permissible concentrations (MPC) and body burdens for some 240 radioisotopes and includes many refinements based on knowledge not available in 1953. The study has included the evaluation of nearly 2,000 separate researches reported in the literature, having bearing on the permissible-dose problem.

The new values reflect, where applicable, the lowering of the basic maximum permissible dose (MPD) recommended by the NCRP in 1957 and 1958. As a result of all of these considerations, some values have been increased, some decreased, and others remain essentially the same. In addition, the calculations have been changed from 70 years continuous occupational exposure to 50 years continuous occupational exposure, a more realistic figure for radiation workers. All maximum permissible concentrations are given for both 40- and 168-hr weeks.

The recommendations in this Handbook are to be considered only as recommendations of a group of experts in the radiological protection field. They carry no legal force requiring or demanding adoption.

Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, National Bureau of Standards Handbook 69 (supersedes NBS Handbook 52), 95 pages, 35 cents, issued June 5, 1959. (Order from Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.)

SINCE metals were first used for industrial purposes, man has waged constant warfare against the forces of corrosion. This complex process has been defined as the destruction of a metal by chemical or electrochemical reactions with its environment; and deterioration often proceeds in direct proportion to the aggressiveness of the environment. Essentially, corrosion is process metallurgy in reverse. Iron, for example, occurs in nature generally as oxides or hydroxide, and is refined to the steels of structural use. When exposed to a corrosive environment, the metal tends to revert to these original forms, which are then called "rust".

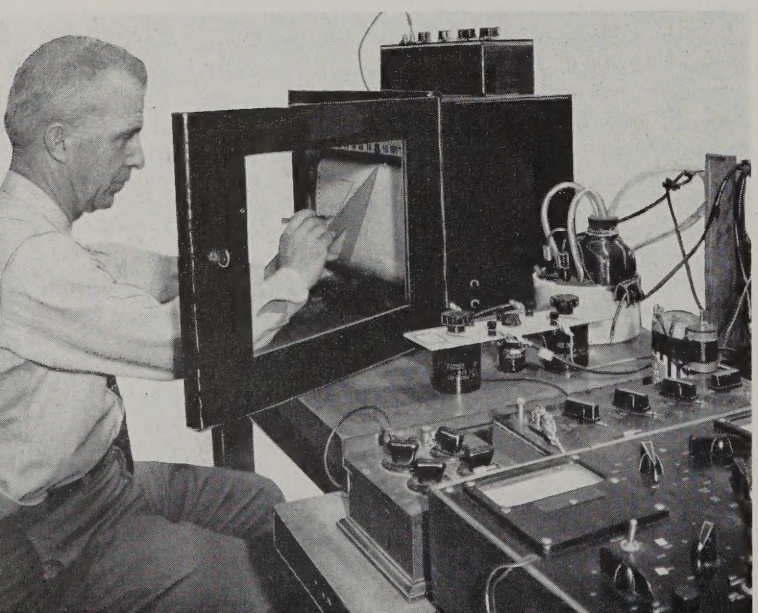
Corrosion is a serious and costly aspect of the Nation's economy. The continuous depletion of ore reserves is only one factor to be considered. Wages, the "down time" of equipment, and replacement costs must also be taken into account. It has been estimated that the annual cost of corrosion in the United States runs to billions of dollars. Of course, exact figures on the total cost are not available, but in the underground pipeline industry alone, reliable estimates show the expense of replacement to be about 600 million dollars a year.

To aid in the solution of this problem, the Bureau has for many years conducted a program of research on the fundamental mechanisms of corrosion and the corrosion properties of materials. Now under the direction of G. A. Ellinger, this program emphasizes basic processes and principles, seeking to discover why metals corrode and how corrosion can be prevented. Current studies deal with such topics as the corrosion reactions at the metal surface, electrochemical polarization and other electrical phenomena associated with corrosion, the effects of free radicals on metals at low temperatures, the nature of corrosion in large single crystals, and the mechanism of stress-corrosion cracking. By attacking the problem from these various directions, the Bureau hopes not only to improve methods of combating corrosion, but also to obtain basic data on the properties of matter that may be useful in other fields.

Left and right: **Oxide crystallites formed on one of the surfaces of a copper single crystal oxidized in water. The symmetrical shapes on part of the surface are indicative of the specimen's crystallographic orientation. (×1,000).** ***Center:*** **Multicolored pattern formed on a copper single-crystal sphere corroded in air-saturated distilled water.**

One of the first corrosion studies at the Bureau was on the "season cracking" of brass, a form of stress corrosion that affects the grain boundaries of brasses in a selective manner. Another early investigation, undertaken at the request of the Congress, explored the electrolytic corrosion of steel by stray electric currents. This work developed into an extensive soil corrosion program, which continued until 1952. More than 300 reports containing information gained during this effort have been summarized and published in NBS Circular 579, *Underground Corrosion.*[1]

One long-range investigation, on the corrosion of aircraft alloys, was started during World War I when metallic materials were first considered for aircraft and is still continuing under the sponsorship of the Bureau of Aeronautics, Department of the Navy.



Polarization techniques are used to determine indirectly the rate of galvanic corrosion. Here the instantaneous rate of corrosion of an iron specimen immersed in salt water is noted by W. J. Schwerdtfeger from the polarization curve obtained with a two-pen recorder.

Single Crystal Studies

As the corrosive process is influenced by many factors, a study of metals in their commercially usable state affords little information on the fundamental nature of the process. Such information can best be derived by studying the least complex form of the metal that has the basic characteristics of the whole, that is, metal in the form of single crystals. In this way, many of the corrosion-influencing factors of polycrystalline materials can be isolated, and reproducible results can be obtained.

Single crystals are being used in research initiated at the Bureau in 1955 under the sponsorship of the Corrosion Research Council. Chosen to investigate the adsorbed layers that form on metal surfaces was the metal-water-oxygen system. Copper was selected as the metal because it has a face-centered cubic structure, is readily available in high purity, and the corrosion products formed are few and simple.

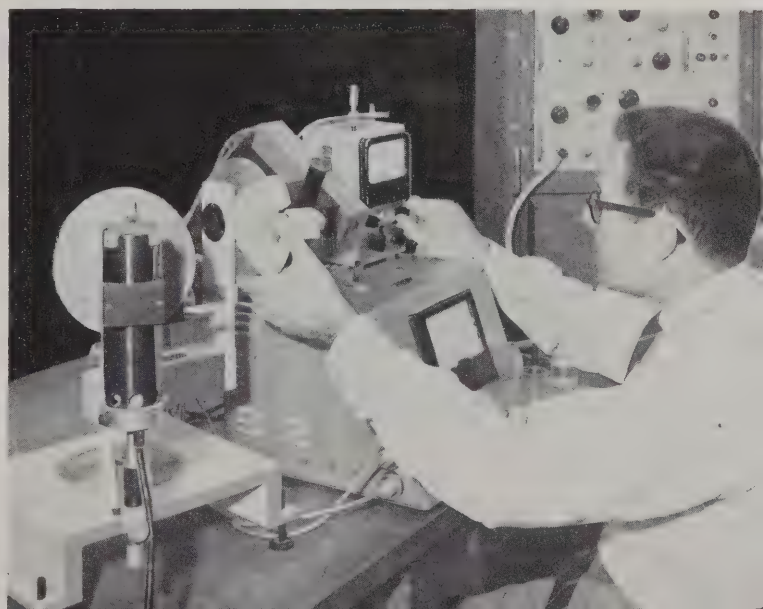
Spherical specimens were initially employed in this work because they permit all of the crystallographic planes to be studied simultaneously. When carefully cleaned and polished specimens are exposed to water containing oxygen, different oxide interference colors appear on the various planes. Each color, readily identifiable from the patterns that are formed, indicates a different rate of growth of the corrosion products.

In one study, experiments were carried out both in open vessels exposed to the atmosphere, and in a closed all-glass apparatus in which the surrounding atmosphere and purity of the water were rigidly controlled.[2] The differences in the composition and nature of the films that formed on similar specimens were attributed to the presence of carbon dioxide in the laboratory atmosphere in the first experiment, and its absence under the controlled conditions of the second. During this study it was discovered that light has a marked inhibiting effect on the corrosion process.[3]

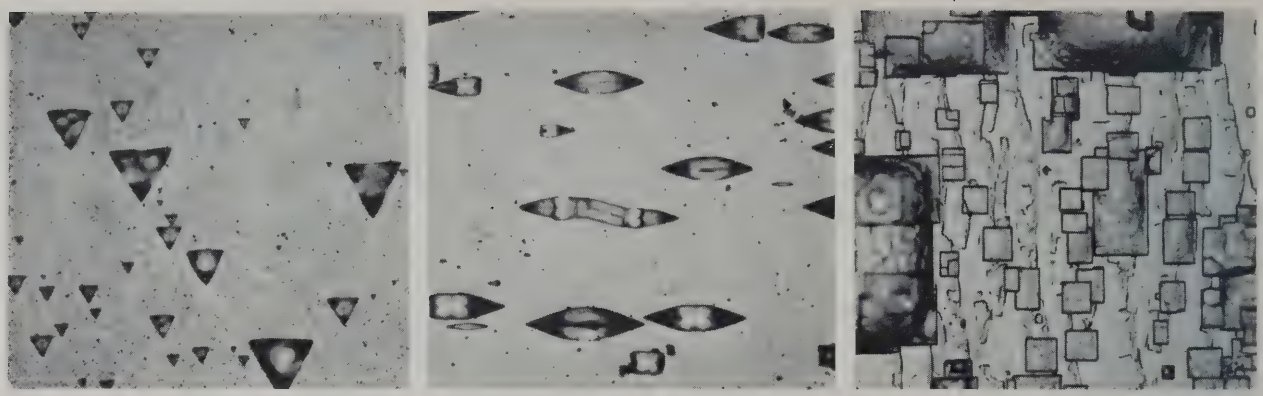
A related effort, undertaken as part of the Bureau's Free Radicals Research Program,[4] is concerned with the influence of atomic oxygen on metals at low temperatures. In this work oxygen is made to pass through a microwave discharge in order to dissociate some of the oxygen molecules. Initial experiments indicate that some reaction does occur between atomic oxygen and copper crystals cooled to 4.2° K. No reaction occurs, however, with oxygen which has not been passed through the microwave discharge. This area of investigation is expected to produce interesting and fruitful results.

In these single-crystal studies, a polarizing spectrometer is used to observe and measure the rate of film growth. This instrument has also been found useful in obtaining data from which the index of refraction of thin gas films can be calculated.

Other work with single crystals has been conducted to study the relationships between surface atomic arrangement and rates of corrosion in acids and alkalies.[5] When large single crystals of high-purity aluminum were exposed to an acid mixture, the configuration of the etch pits that formed on the surfaces differed according to the crystallographic orientation of the specimen. The rates of corrosion on these surfaces varied radically from the rates observed on atomically similar surfaces exposed to an alkali mixture.



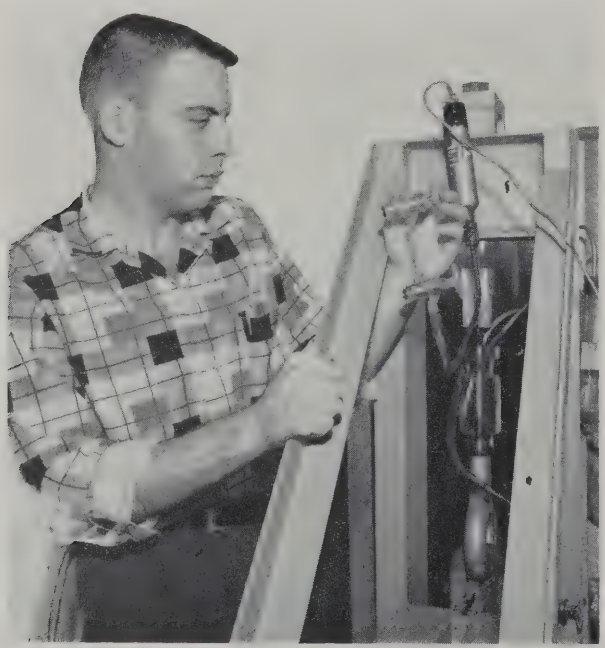
Corrosion reactions on the surface of metal single crystals are studied with this polarizing spectrometer. Jerome Kruger is making potential measurements while simultaneously measuring film thickness with the spectrometer. The specimen is held in the apparatus at left.



Etch pits formed on surfaces parallel to the three principal crystallographic planes of an aluminum single crystal. The specimens were exposed to an aqua regia-hydrofluoric acid mixture. (×200).

During an experiment with the corrosion of monocrystalline copper in an acid,[6] copper was electrodeposited on the specimen surfaces in an attempt to more readily distinguish the facets exposed as a result of attack in the acid. An analysis of Laue back-reflection diffraction patterns showed that the microstructure of the deposit either duplicates the orientation of the base crystal or has a continuing and twinned relationship with it. During the course of this research, equipment was developed for growing preferentially oriented metal monocrystals of practically any cross-sectional shape.[7] A preselected orientation was obtained with a technique known as "seeding", and the desired cross-sectional shape was produced by growing the crystals in a vertical furnace.

The role played by hydrogen in stress-corrosion cracking is studied with this apparatus. Joseph Himes is checking the vacuum system for possible leaks. An unstressed specimen is in glass container, right center.



Galvanic Corrosion

Even the purest metals have many foreign atoms within their lattices. Less pure metals contain nonmetallic inclusions, metallic impurities, and other inhomogeneities. Exposure to a corrosive medium of dissimilar metals in contact with each other, or of a metal with surface inhomogeneities, causes galvanic (electrochemical) corrosion. Such corrosion can also occur on metal surfaces exposed to nonuniform electrolytes with variations in electrical conductivity, etc. The electrical current associated with corrosive action causes the metallic area with the more anodic solution potential to dissolve, forming a pit in the metal surface. The depth of pitting depends on the amount of current that flows from anode to cathode, which in turn may depend on several factors such as anode to cathode area, environment, temperature, and pressure. When the mechanism that causes the first pit to form can be determined, a great advance will have been made in understanding the corrosion process.

Galvanic corrosion which occurs on a continuous metallic surface cannot be measured directly. However, the Bureau has developed a method for evaluating this corrosion indirectly, on ferrous surfaces at least.[8] In this method, the currents associated with the changes-in-slope in current-potential curves that occur during cathodic and anodic polarization are measured, and the values of applied polarizing current thus obtained are used to calculate the equivalent corrosion current. This indirect technique has been successfully applied in measuring the corrosion rates of steel in low-resistivity soils and in salt water. A variation of 10 percent in corrosion rate can be detected in this way.

Now under investigation are the polarizing characteristics of iron specimens alloyed with, in various amounts, up to 20 percent chromium, together with a similar series that contains, in addition, 3.5 percent of silicon. Efforts will be made to use the indirect polarization technique to evaluate other factors affecting corrosion rates. Such factors include temperature, aeration and motion of the electrolyte, heat treatment, and alloying constituents of the basis metal.

Disks (held at left) are cut from the aluminum single crystal (large bar) and highly polished. The shapes into which the specimens corrode (foreground) depend on both the orientation of the specimen and the corrosive medium. Spherical specimen (above bar) corrodes in the shape shown to the right when exposed to an aqua regia-hydrofluoric acid mixture.

One galvanic corrosion study deals with criteria for the cathodic protection of metals, principally ferrous metals. Although cathodic protection is based on well-founded scientific principles, its application has been the subject of considerable discussion. Insufficient negative potential gives inadequate protection, yet maintaining a greater potential than is required is unnecessarily costly. In investigating the problem, Bureau scientists have made a series of electrical measurements to evaluate the criteria of cathodic protection.[9]

In a part of this work it was found that steel exposed to soil environments varying in *p*H between 2.9 and 9.6 can be protected from corrosion by maintaining the steel at an electrical potential of −0.77 v relative to a saturated calomel reference cell. Recent laboratory experiments showed that −0.77 v is also the optimum potential for protecting steel in salt water.[10]

Stress Corrosion

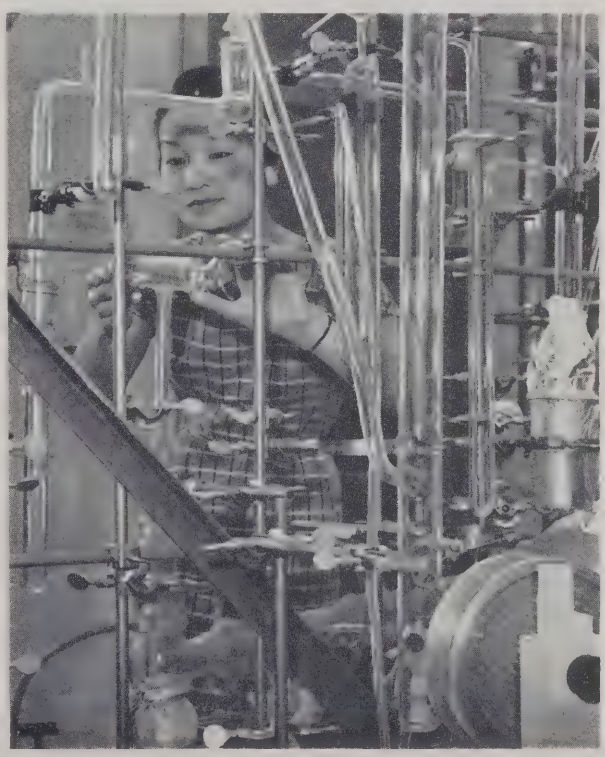
The crystal structure of metals has a direct bearing on stress-corrosion cracking, a particularly damaging type of failure resulting, as its name suggests, from the combined effects of stress and corrosion. Cracking may be either intercrystalline, as in aluminum alloys and low-carbon steels, or transcrystalline, as in magnesium alloys and stainless steels. Of particular interest are the copper-zinc alloys, in which the attack is intercrystalline in the alpha phase and transcrystalline in the beta phase.

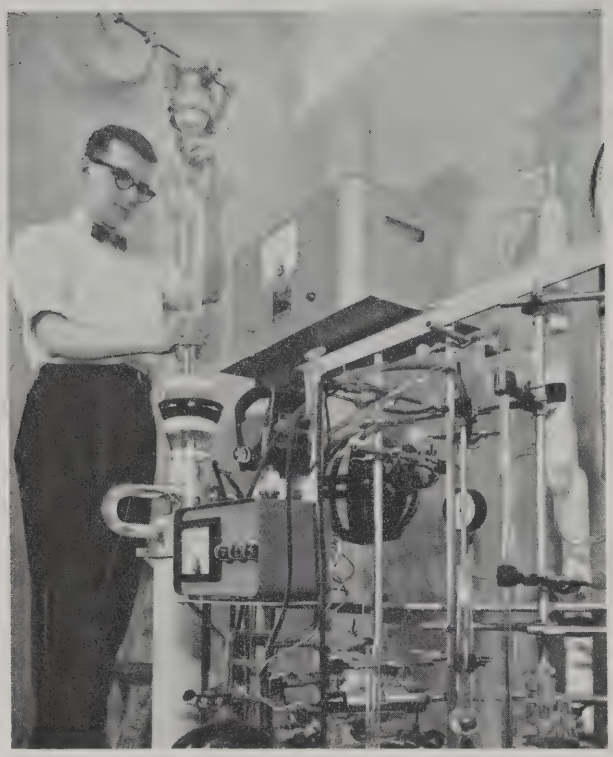
Residual or applied tensile stresses—frequently far below the yield strength of the material—may produce this type of failure even though the corrosive effect itself is very mild. Specific environments are often required, but in some cases a number of different media may cause cracking. Most investigators agree that practically all metals and alloys are subject to this failure when the necessary combination of stress and corrosion is present.

When most metals are exposed to ordinary atmospheres, a thin oxide covering quickly forms that tends to protect the metal from further corrosion. Stress-corrosion cracking apparently starts with a scratch or break in the protecting film. In investigating this type of cracking in several metals, the Bureau found that the process usually is continuous to complete failure.[11] However, if shifts in stress concentrations permit repair of the film from time to time, the process may be discontinuous.

For years stress-corrosion cracking has been a problem in the production of wrought-brass articles. During spinning and deep drawing, stresses are set up which remain in the metal unless removed by annealing. In studying this problem, the relationship between crystallographic orientation and cracking of both alpha and beta brasses was investigated.[12] Experimental results showed that the intercrystalline cracking in alpha brass apparently depends on the relative orientation of the crystals bordering the cracks, and hence on the crystal boundary energy. In beta brass, transcrystalline cracking occurs in crystals oriented most favorably for slip, and in planes that are approximately normal to the applied stress.

June Y. Chung evacuates the apparatus used for studying film growth on copper single crystals.





Part of the equipment used in single crystal research for the free radicals program. W. J. Ambs is inserting a liquid helium cold finger into the apparatus to study the effect of atomic oxygen on metals at low temperatures.

Experiments conducted for the Corrosion Research Council with a magnesium alloy indicated that the development of cracking is dependent upon strain rate.[13] However, these studies present very strong evidence that stress corrosion is partly an electrochemical phenomenon and not one of mechanical fracture only.

Recent work on austenitic stainless steels[14] for the Pressure Vessel Research Committee disclosed that sporadic but repeated creep in favorably oriented areas may rupture the protective film. This rupture provides a small film-free anodic area where stress corrosion can begin. By making the stressed steel become the anode in an external circuit, the corrosion can be accelerated. On the other hand, the corrosion can be prevented or stopped by application of a cathodic current.

Stress corrosion studies include exposure of specimens, principally aircraft alloys, to an urban atmosphere at Washington, D.C., and to a marine atmosphere on the Atlantic Ocean at Kure Beach, North Carolina. These studies are quite limited, however, in comparison to the main effort, directed toward developing fundamental data on the complex corrosive process.

Future Plans

In the near future, the Bureau expects to investigate corrosion inhibitors of the precipitate or barrier type. This work will explore the kinetics and energy associated with the formation of the precipitate, and the forces binding it to a metal surface. Additional corrodents will be studied in the work on aluminum single crystals, and single-crystal research will be extended to other high-purity metals.

A specimen in which most of the variables can be controlled has been devised for future stress corrosion studies. Investigations have been started on the influence of temperature and high pressures on the mechanism and kinetics of metal oxidation, as well as additional work on the reactions between atomic oxygen and metallic surfaces. The results of these and related studies are expected to provide science and industry with solutions to some of the practical corrosion problems that are causing concern today.

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[1] *NBS Circ. 579 is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. ($3.00). See also* Underground corrosion, *NBS Tech. News Bul.* **42,** *181 (1958).*

[2] The oxide films formed on copper single crystal surfaces in pure water: 1. Nature of films formed at room temperature, *by J. Kruger, J. Electrochem. Soc. (in press)*; Some basic corrosion research at NBS, *by J. Kruger, Ind. and Eng. Chem.* **50,** *55A (1958).*

[3] Effect of illumination on the oxidation of copper single crystals in water, *by J. Kruger, J. Appl. Phys.* **28,** *1212 (1957)*; Retardation of copper corrosion by light, *NBS Tech. News Bul.* **42,** *47 (1958).*

[4] Free radicals research program, *NBS Tech. News Bul.* **41,** *1 (1957).*

[5] Influence of crystallographic orientation on the corrosion rate of aluminum in acids and alkalies, *by T. H. Orem, J. Research NBS* **58,** *157 (1957) RP2748.*

[6] Twinned epitaxy of copper on copper, *J. Research NBS* **60,** *597 (1958) RP2873.*

[7] Growth of preferentially oriented aluminum crystals, *J. Research NBS* **60,** *547 (1958) RP2868;* Growth of metal single crystals, *NBS Tech. News Bul.* **43,** *136 (1959).*

[8] Measurement of the corrosion rate of a metal from its polarizing characteristics, *by W. J. Schwerdtfeger and O. N. McDorman, J. Electrochem. Soc.* **99,** *407 (1952)*; Electrical measurement of corrosion rate, *NBS Tech. News Bul.* **37,** *22 (1953)*; Measurement of the corrosion rate of iron by polarization techniques, *by W. J. Schwerdtfeger, J. Research NBS* **58,** *145 (1957) RP2746.*

[9] Potential and current requirements for the cathodic protection of steel in soils, *by W. J. Schwerdtfeger and O. N. McDorman, J. Research NBS* **47,** *104 (1951) RP2233; NBS Tech. News Bul.* **36,** *1 (1952).*

[10] Current and potential relations for cathodic protection of steel in salt water, *by W. J. Schwerdtfeger, J. Research NBS* **60,** *153 (1958) RP2833; NBS Tech. News Bul.* **42,** *83 (1958).*

[11] Film rupture mechanism of stress corrosion, *by H. L. Logan, J. Research NBS* **48,** *99 (1952) RP2291; NBS Tech. News Bul.* **36,** *54 (1952).*

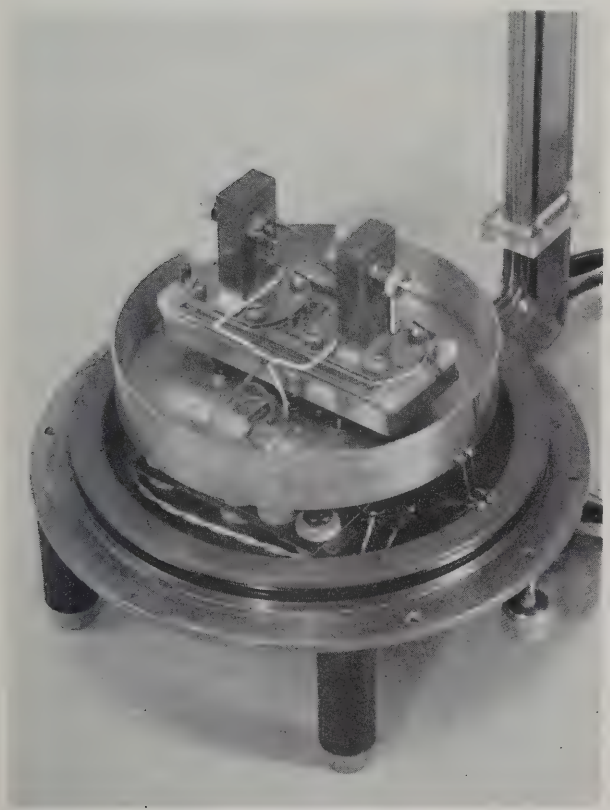
[12] Relationship between crystal orientation and stress corrosion cracking in alpha and beta brasses, *by H. L. Logan, J. Research NBS* **56,** *159 (1956) RP2662;* Stress-corrosion cracking of brass, *NBS Tech. News Bul.* **40,** *109 (1956).*

[13] Mechanism of stress corrosion cracking in the AZ31B magnesium alloy, *by H. L. Logan, J. Research NBS* **61,** *503 (1958) RP2919; NBS Tech. News Bul.* **43,** *63 (1959).*

[14] Studies of stress corrosion cracking of austenitic stainless steel, *by H. L. Logan, Welding J.* **37,** *Research Suppl. 463S (1958).*

Recent International Comparisons of Microwave Power Standards

RECENT developments in the field of microwave power measurements at the Bureau's Boulder (Colo.) Laboratories have made possible the participation of the United States in the implementation of a long standing resolution of the International Scientific Radio Union (URSI). This resolution, which recommends the international intercomparison of power standards in the microwave region, was adopted more than 10 years ago and has been reaffirmed at each following general (international) assembly. The text of this resolution by the 12th General Assembly, which met at Boulder in the autumn of 1957, is as follows: "It is strongly recommended that the national laboratories should intercompare their standards of power measurement at frequencies in the neighborhood of 3,000 Mc and 10,000 Mc. The comparisons to be coordinated by Dr. R. L. Smith-Rose, Director, Radio Research Station, Ditton Park, Slough, Bucks, England."



Interior of the refined microwave microcalorimeter used in the recent international comparisons of microwave power standards.

The Japanese delegates to this 12th General Assembly of URSI brought with them an X-band microwave power standard and requested that it be compared with a similar standard at the Boulder Laboratories. The Japanese standard took the form of a bolometer (barretter) mount which had been calibrated in Japan by microcalorimetric and impedance methods.

In December 1957, the Japanese mount was compared with a similar NBS bolometer (barretter) mount by observing the power indicated by each when alternately connected to a signal generator of constant output amplitude. The NBS mount was calibrated by a refined X-band microcalorimeter which had been recently placed in operation at the Boulder Laboratories.

The results of this intercomparison showed a discrepancy which was several times larger than the estimated limits of error for the individual measurements and was tentatively attributed to the comparatively long time which had elapsed between the measurements in the two countries.

More recently (July 1958), an NBS standard bolometer mount of improved design, which had been calibrated by the Bureau's microcalorimeter and by an improved version of D. M. Kerns' impedance method, was sent to the Radio Research Station in England for intercomparison at a frequency of 9,375 Mc. The "effective efficiency" of this mount as determined by the Boulder Laboratories of the National Bureau of Standards was 98.5 percent. The corresponding value for the effective efficiency obtained by the Radio Research Station in England was 97.2 percent. This discrepancy is within the estimated limits of error for the individual measurements, or in other words, the United States and United Kingdom power standards at X-band agree within 1.3 percent.

NOTE: *For a complete description of this work, see* A refiined X-band microwave calorimeter *by G. T. Engen, J. Research NBS* **63C**, 77 *(1959)*.

NEW RADIUM SOLUTION STANDARDS

THE Bureau has added a new series of 10^{0}- and 10^{-11}-g radium standards to the list of radioactive samples it prepares and distributes.[1] These radium solutions were prepared recently by W. B. Mann, L. L. Stockmann, and A. Schwebel of the radioactivity laboratory.[2] This new series was made up to restock the nearly depleted and less accurate 1940 supply of radium standards in this range. To provide standards with activities between the 10^{0}-g and 10^{-11}-g values, new "blank solutions", containing 0.02×10^{-12}-g of radium, have also been made available for dilution purposes.

These radium solution standards were issued as part of the Bureau's program to supply standards in all areas of the physical sciences. Radioactivity standard samples, such as these, are especially important, being widely used in the fields of physics, chemistry, biology, and medicine to control processes and maintain accurate equipment and apparatus.

[1] *The samples may be obtained from the Radioactivity Section, National Bureau of Standards, Washington 25, D.C. Prices are: radium standard samples, $27.00; blank solutions, $5.00. Further information is contained in Standard Materials, NBS Circ. 552 (third edition), which may be obtained by writing to the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. (35 cents).*

[2] Preparation of new solution standards of radium, *by W. B. Mann, L. L. Stockmann, W. J. Youden, A. Schwebel, P. A. Mullen, and S. B. Garfinkel, J. Research NBS* **62,** *21 (1959) RP2924.*

Packaging the radium solution standard samples used in controlling industrial and scientific processes. L. L. Stockmann signs a certification of the radium content which accompanies each sample issued.

NEW PUBLICATION:
Checking Prepackaged Commodities, A Manual for Weights and Measures Officials

THE CONTROL of the accuracy of quantity in packages is a specialized, yet extremely vital, phase of weights and measures administration. This Handbook is an operational guide for the control, under law, of prepackaged commodities. It includes information on equipment, techniques, action, reporting, and, as an appendix, a comprehensive table that will facilitate the checking of total selling prices when these are based on extensions of stipulated unit prices.

Although this publication has been prepared primarily for use by weights and measures officials of the states, counties, and cities, it is believed that the information presented will be useful to persons employed by commercial and industrial establishments involved in the packing, distributing, and retailing of packaged commodities.

This is the fifth in a series of NBS Handbooks designed as comprehensive guides for state and local weights and measures officials, in accordance with the Bureau's statutory responsibility to promote uniformity in weights and measures laws and methods of inspection. In order to facilitate the use of the manual and price computation table in field inspections, the Handbook has been published in "pocket" size.

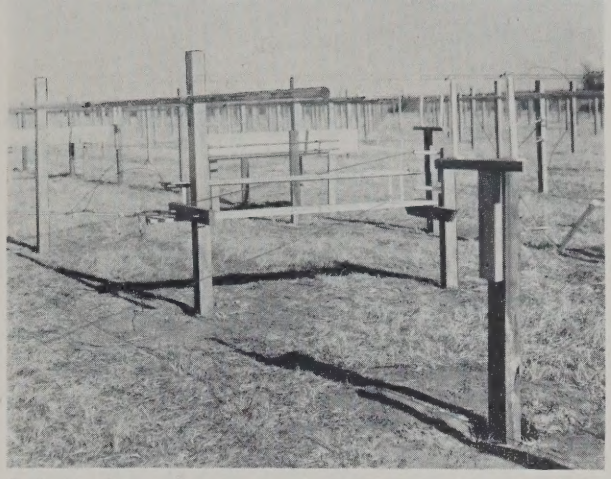
Checking Prepackaged Commodities, A Manual for Weights and Measures Officials, National Bureau of Standards Handbook 67, 27 pages, issued March 20, 1959, 35 cents. (Order from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.)

Vertical Incidence Scatter from the Ionosphere

THROUGH application of special radar techniques, the Bureau has developed a promising method for studying physics of the upper reaches of the ionosphere. The method uses very-high-frequency waves, most of which pass through the ionosphere, including those layers which reflect lower-frequency transmissions. In this passage, part of the energy of the vhf waves excites electrons in the upper atmosphere—above heights of 50 miles. This causes re-radiation, or "scatter", which returns low-power radio waves to earth. A high-power, vhf radar transmitter and special antenna, built under the direction of Kenneth L. Bowles of the Bureau's Central Radio Propagation Laboratory (Boulder, Colo.) are used to observe the vertically returned scattering. The equipment is located near Long Branch, Ill.

This method of observing vertically returned scattering permits studies of ionization at all levels of the atmosphere, even above reflecting layers, well into outer space. Recent preliminary experiments detected the results of scattering from as far up as 400 miles. Refinements of the experimental setup are expected to extend this range.

Until these experiments, radar-type ionospheric soundings depended on observation at high frequencies (3 to 30 Mc) of intense reflections from ionospheric layers dense enough to reflect the wave completely. Thus, until now, studies have largely been confined to determinations of the heights and characteristics of the "maximum density" layers of the ionosphere.

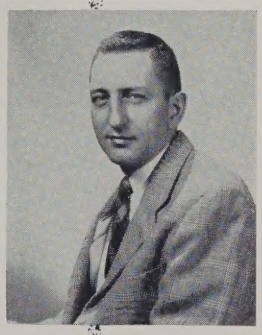


Individual dipoles, part of 4-acre array autenna at Long Branch, Ill. This antenna, consisting of 1,024 dipoles, will be used to study the physics of the upper reaches of the ionosphere.

In principle, the technique should extend knowledge of the ionosphere by making possible temperature as well as electron-density measurements of the upper atmosphere. Such observations can serve to confirm rocket-derived measurements but are more suitable than rocket-mounted instruments for long-term studies of changes in the ionosphere due to diurnal, seasonal, and solar activity variations.

Signals at a frequency of 41 Mc, generated by a transmitter capable of delivering 6-million w peak power, are pulsed into the fixed antenna and then into space. The beam width of the antenna is approximately 4 deg. Pulses range from 50 to 150 μsec in duration and are repeated at a rate sufficient to maintain an average power of 40,000 w. Four acres of land are covered by the antenna array which is composed of 1,024 half-wave dipoles, 4½ ft above a ground-reflecting screen. Operation of the antenna was checked by total power recordings from the radio point source in the constellation Cygnus (Cygnus A) which happens to pass through the center of the beam.

CASSEL RECEIVES ALSOP AWARD



JAMES M. CASSEL of the Leather Section, Organic and Fibrous Materials Division, is the recipient of the Alsop Award for 1959. This award, which is the highest honor given for meritorious work in the field of leather chemistry, was presented at the annual meeting of the American Leather Chemists Association at Mackinac Island, Michigan, June 14–17, 1959. The award is based on Mr. Cassel's work on the development of a chromatographic procedure for determining quantitatively each of the amino acids in collagen and for his work on the mechanism of degradation of collagen by heat and gamma radiation.

Mr. Cassel was born in New Kensington, Pennsylvania, November 21, 1918. Upon his graduation from Washington and Jefferson College in 1942, he entered the Marine Corps where he served for four years. He joined the staff of the Bureau in 1946 and received his M.S. in chemistry from Georgetown University in 1954.

He is a member of the American Chemical Society and the American Leather Chemists' Association, and is active on a number of the Association's technical committees.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, see listing below.

Technical News Bulletin, Volume **44,** No. 6, June 1959. 15 cents. Annual subscription $1.50, 75 cents additional for foreign mailing.

Basic Radio Propagation Predictions for September 1959. Three months in advance. CRPL–D178. Issued June 1959, 10 cents. Annual subscription $1.00, 50 cents additional for foreign mailing.

Journal of Research

Section A. Physics and Chemistry, Volume **63A,** *No. 1, July—August 1959 (Annual subscription: Domestic $4.00; foreign, $4.75). Approx. issue date August 3, 1959*

Description and analysis of the first spectrum of iodine. C. C. Kiess and C. H. Corliss.

CH in the solar spectrum. Charlotte E. Moore and H. P. Broida.

Infrared studies in the 1- to 15-micron region to 30,000 atmospheres. C. E. Weir, E. R. Lippincott, A. Van Valkenburg, and E. N. Bunting.

Phosphinoborine compounds: mass spectra and pyrolysis. L. A. Wall, S. Straus, R. E. Florin, F. L. Mohler, and P. Bradt.

Experimental and theoretical study of kinetics of bulk crystalization in poly (chlorotrifluoroethylene). J. D. Hoffman, J. J. Weeks, and W. M. Murphey.

Section B. Mathematics and Mathematical Physics, Volume **63B,** *No. 1, July—September 1959 (Annual subscription: Domestic $2.25; foreign $2.75). Approx. issue date September 8, 1959.*

Relations between summation methods and integral transformations. W. Greub.

On a modification of Watson's lemma. F. Oberhettinger.

Principal submatrices of a full-rowed non-negative matrix. K. Goldberg.

Zeros of certain polynomials. A. J. Goldman.

Tables of transport integrals: A supplement. W. M. Rogers, W. J. Hall, and R. L. Powell.

Lens design: A new approach. O. N. Stavroudis.

Analytical integration of the differential equation for water storage. V. M. Yevdjevich.

Compressible turbulent boundary layers with heat transfer and pressure gradient in flow direction. A. Walz.

Section C. Engineering and Instrumentation, Volume **63C,** *No. 1, July—September 1959 (Annual subscription: Domestic $2.25; foreign $2.75). Approx. issue date August 17, 1959.*

Creep of cold-drawn nickel. W. D. Jenkins and C. R. Johnson.

Friction and endurance of prelubricated and unlubricated ball bearings at high speeds and extreme temperatures. H. S. White.

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Section D. Radio Propagation, Volume **63D,** *No. 1 July–August 1959 (Annual subscription $4.00; foreign $4.75). Approx, issue date July 13, 1959.*

Preliminary results of the National Bureau of Standards radio and ionospheric observations during the International Geophysical Year. D. M. Gates.

Origin of [OI] 5577 in the airglow and the aurora. F. E. Roach, J. W. McCaulley, and E. Marovich.

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Low-frequency propagation paths in arctic areas. A. D. Watt, E. L. Maxwell, and E. H. Whelan.

Circulars

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Technical Notes

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TN7 (PB151366). Low- and very low-radiofrequency tables of ground wave parameters for the spherical earth theory: The roots of Riccati's differential equation. (Supplementary numerical data for NBS Circ. 573). J. R. Johler, L. C. Walters, and C. M. Lilley. $2.25.

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